Projections of Economic Competitiveness of Nuclear Power

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Over the last ten years the performance records of the currently operating nuclear plants have improved considerably, and the economic environment in the electric sector has recently become more favorable. Consequently, the prospects for the construction of new nuclear power plants in the industrial and industrializing countries, even before the end of this decade, are the best they have been over the last thirty years. The economic factors affecting the decisions to commit to new nuclear power plants construction are reviewed in this text.

New Environment for Operating Nuclear Plants

The economic and safety performance records of the currently operating nuclear plans worldwide have continuously improved over the last decade, as demonstrated by the World Association of Nuclear plant Operators (WANO).WANO, which is an international utility self-help organization concentrating on plant experience sharing and best practices transfers, has been measuring both operating and safety performance records of nuclear plants worldwide. Its statistics show a world-wide continuously improving trend over the last eleven years, as regards increased plants availability, lower operators' exposure, declining numbers of safety-related plant shutdowns and reduced rate of industrial safety accidents. In parallel with these improved plant operating and safety records, various countries report improved economic performance of their nuclear power plants. In the United States, the Nuclear Energy Institute (NEI) has been measuring plants capacity factors and production costs (sum of operating and maintenance (O&M) costs and fuel expenses) over the last decade. Its data indicate an almost monotonic improvement trend in annual capacity factors and in total generation of the entire U.S. nuclear plants fleet – over 100 units – the largest nuclear plants fleet in the world – since 1985. In 2002 the U.S. nuclear plants have operated at a fleet average capacity factor of 91.5 percent, and have generated 780 Billion KWh, representing 20.3 percent of total generation. Nuclear plants' production costs have continuously declined since 1987, in part due to the improved capacity factors, and more importantly, due to a concerted industry initiative to reduce operating costs and achieve higher excellence in plants operation. In 2001 (last year of published data) the nuclear plant fleet average production cost has declined to 1.68 Cents/KWh, with the best quartile plants demonstrating a three-years average (1999-2001) production cost of 1.33 Cents/KWh. The continuing improvements trend in U.S. and European countries' nuclear programs (e.g. Finland, Sweden, Switzerland), has been successfully emulated in other world regions – witness the success of the Korean and Chinese nuclear programs. These records provide the necessary background for the current recognition in various countries that a new expansion of the global nuclear capacity is both an acceptable and a desirable policy option.

The new willingness to consider a revived nuclear plants construction program is also based on the recently changing operational environment within the electric utilities industry. The capacity surplus created by the large gas-fired plants construction program is expected to be worked-off towards the end of the decade (When new nuclear plants could come on-line), as the emerging economic recovery will increase electric demand, and as economically unsound projects are cancelled. The uncertainty regarding electric sector deregulation, following the failed restructuring program in California and the collapse of Enron and the electricity trading business, will be resolved as the Federal Energy Regulatory Commission (FERC) proceeds with its standard Market Design (SMD) initiative, and the experience from successful restructuring program such as in the Pennsylvania, Jersey, Maryland (PJM) Interconnect is absorbed within the electric utilities system. More importantly, the major competitor to nuclear power plants – the natural gas fired combined cycle plants (CCGT), are now encountering problem due to the inability of the gas industry to find new gas resources, drill new gas wells, and bring new gas supplies to the expanding natural gas markets. Consequently, natural gas prices have increased from the long-term expected value of 3.5 $/MMBTU to a new range of 5.0 – 6.0 $/MMBTU, and future gas prices, at least until the end of this decade, are expected to fluctuate around these high price values. In this new and unstable fuel supply operating regime, the basic values of nuclear plants – their low and stable fuel prices, ample fuel supplies, and excellent and stabilizing plant operating records – are being recognized again. There is a value attached to low price volatility electricity source such as nuclear power, which makes it a desirable candidate for long-term bilateral supply contracts with energy consumers. Hence the new opening for new nuclear plants construction program within this decade – the Nuclear 2010 initiative.

Competitiveness of New Nuclear Plants Against Gas-Fired CCGTs

The economic competitiveness of new nuclear power plants based mostly on Advanced Light Water Reactor (ALWR) technologies, have been evaluated in several countries now considering the expansion of their nuclear generating capacity. Finland, which has initiated in 2002 an international bid for its fifth nuclear power plant, has based this initiative on computations indicating that a new nuclear plant ought to be more economic than either a new coal or a new natural gas fired power plant. Finnish analysis indicates that the electricity generation costs of a new ALWR are now estimated at 22.3 Euros/MWh, whereas the generation costs of a new coal or gas fired plants are estimated at 24.4 and 26.3 Euros/MWh, respectively. The NEI has estimated the generation costs of a U.S. CCGT plant as a function of natural gas price, and compared them with the production costs of a currently operating nuclear plant. At the low gas price of 2.5 $/MMBTU, the total generation costs (including capital, fuel, and O&M expenses) of a CCGT plant are estimated at 33 $/MWh. At the current gas price of 5.0 $/MMBTU the CCGT plant generation costs increase to 51 $/MWh, and at the relatively higher gas price of 7.5 $/MMBTU CCGT generation costs reach 68 $/MWh. This compared with the production costs of an existing nuclear power plant of 25 $/MWh. Evidently, it does not make sense to prematurely shut down an operating nuclear plant and replace it with a new CCGT plant, even if natural gas prices dip down to the low value of 2.5 $/MMBTU (lower than the expected long-term equilibrium price value). This is so far as the competition between existing nuclear plants and new CCGT plants are concerned. Can a new nuclear plant – an ALWR – compete against a new CCGT plant in a head-to-head economic competition for a future new power plant commitment?

This issue was explored at some length by the Near Term Deployment Group (NTDG) of the Department of Energy (DOE) Generation IV Roadmap Study. The NTDG Study conducted in 2001-2002, has laid out the technical background in support of the DOE Nuclear 2010 initiative. The economic part of the NTDG Study has explored the relative competitiveness of 1,000 MWe plus nuclear power plants based on (mostly) ALWR technologies against similar capacity natural gas fired CCGT plants, as functions of ALWR capital costs and natural gas prices. Both types of plants represent new commitments, expected to reach commercial operation by 2010. The generation costs of both types of plants were computed using the NEI power plants costs computation model, and a standard set of economic assumptions equally applicable to the nuclear and the gas fired plants. The

NTDG has explored a range of ALWR capital costs and a range of natural gas prices that will yield similar generation costs for both types of plants. This procedure is equivalent to a break-even generation costs type of an analysis.

The results of the NTDG economic evaluation study indicate that (all other factors held constant), an ALWR with an engineering, procurement and construction (EPC) capital cost of 1,000 $/KWe (excluding contingency and owners costs) will be competitive with a CCGT plant burning natural gas priced at 3.8 $/MMBTU, both plants demonstrating total generation costs of about 41.5 $/MWh. In similar fashion, an ALWR with an EPC capital cost of 1,200 $/KWe will be competitive with a CCGT plant burning gas at 4.8 $/MMBTU, both plants demonstrating total generation costs of 47.5 $/MWh. The parametric ranges of capital costs and fuel prices were extrapolated beyond the values reported above. The two sets of ALWR capital and generation costs mentioned here do represent the range of expected costs of new nuclear plants currently offered in the market. The higher cost figures are typical of large ALWRs currently being built in international projects. The lower capital and generation cost figures are typical of new ALWR and heavy water reactor designs, now undergoing Design Certification reviews by the Nuclear Regulatory Commission (NRC), and expected to be commercially offered in the market within the next two or three years. It should be mentioned that at current high natural gas prices (above 5.0 $/MMBTU), assuming these high prices hold in the long term, all ALWR and heavy water plants (and also High Temperature Gas Fired Reactor plants (HTGRs)), will be more than competitive against natural gas burning CCGT plants. A major uncertainty, though, is how will natural gas prices fluctuate in the future.

Two other factors may provide additional competitive margin for future new nuclear plant commitments: Firstly, clean air act amendments and fossil-fired plants' emissions reduction legislation may increase the costs power plants burning organic fuels, due to the imposition of advanced emissions control technologies – carbon sequestration, due to the transition to advanced power plant technologies – the integrated gasification and combined cycle (IGCC) plants, or due to the enactment of carbon tax legislation. The higher costs of fossil fired power plants due to any of the above factors or a combination of all will increase the break-even capital costs of future advanced nuclear power plants. Secondly, expected electricity transmission bottlenecks among different regions of the U.S. will create local supply shortage situations which will result in scarcity driven higher market prices. New nuclear plants installed to alleviate such shortages, and especially well suited for base-load operation and uninterrupted electricity generation at low marginal costs, will thus obtain higher market clearing prices (MCPs). Such higher MCPs (above normal values due to shortage situations), will help defray the initially higher capital costs of nuclear plants as compared with the lower capital costs fossil fired plants. Once the initial nuclear plant capital costs are paid out and depreciated, nuclear plants due to their low production costs will become very economic to operate in a market-based environment, as the previously mentioned NEI economic analysis has indicated.

Margin Analysis of New Nuclear Power Plants

A different perspective on nuclear power economics can be obtained by a procedure referred to as margin analysis. The margin here is the difference the market prices obtained by the plant from the sale of electricity in the wholesale or local markets, and the plant's all inclusive production costs. All inclusive production costs include all the annually expensed charges incurred in operating the plant – fuel costs, O&M expenses, general and administrative (G&A) costs, annual inventory charges on fuel stockpiles held by the plant, capital additions and interim replacement costs, etc. The difference between the revenues coming in on an annual basis, and the yearly total operating costs, is the margin available to the plant owners from which to pay the capital costs associated with building the plant to start with, and from which to obtain net profits (if any). This margin concept is referred to by utility economists as the equivalent of capacity charges, is referred to by accountants as earnings before income taxes depreciation and amortization (EBITDA), and is referred to in the construction industry as gross margin. These different nomenclatures all relate to the same concept which we will refer to as the margin.

A conservative margin analysis carried out by NEI assumes relatively low electricity sales price – unit revenues – of 35 $/MWh, and relatively high nuclear production costs (all inclusive) of 27 $/MWh, leaving a margin of 8 $/MWh. A 1,300 MWe nuclear plant operating at about 90 percent capacity factor will generate annually 11 Million MWh. Thus the margin provided by that plant, under the assumptions mentioned above, will amount to about 88 Million Dollars on an annual basis. This analysis is overly conservative. Wholesale electricity prices in many regions of the U.S. now far exceed the value estimated above by the NEI. We have assumed a less conservative and more representative value of 43 $/MWh. In like fashion, the operating cost figure assumed by NEI was overly conservative since the best quartile plants now operating have already demonstrated production costs of 13.3 $/MWh and future ALWRs are assumed to do even better. We have assumed a less conservative (though still higher than industry expectation) operating cost of 19 $/MWh. Thus the choice of less conservative and more realistic, but by no means optimistic assumptions, results in a larger and more realistic margin of 24 $/MWh, which translates to 264 million dollars on an annual basis for a large sized nuclear plant. Will this less conservative and more realistic margin suffice to pay the capital cost of the large new ALWR considered here?

To evaluate this issue it is possible to compute the annual cost required to pay off the initial capital cost of a large ALWR. A sample computation we have performed assumes a 1,300 MWe nuclear plant with an EPC cost of 1,100 $/KWe, and an overnight cost of about 1,400 $/KWe (including contingency and owners costs). The total cost of constructing such plant, including interest during construction over a four years site construction period is estimated here as about 2.2 Billion Dollars. This initial capital cost can be converted into a mortgage-type stream of fixed annual capital charges that need to be paid off during the operating life of the plant, using a fixed charge rate factor, expressed in units of percent per year. Typical values of annual fixed charge rate factors vary between 11 percent per year in a regulated environment, and 15 percent per year in a market environment for an nth-of –a-kind (NOAK) nuclear plant. (An NOAK plant is considered the fifth in a series of single-unit plants or the third in a series of two-unit plants). When applying the fixed charge rate factors to the initial plant capital cost figure computed above, we find that the annual fixed charges that will have to be paid out amount to 240 to 330 Million Dollars, depending on whether the plant will be built in a regulated or deregulated market environment. This range of annual capital charges will have to be covered by the margin between incoming revenues and operating expenses, as discussed above. We have found that under less conservative but not really optimistic assumptions, as compared with the initial NEI analysis, an ALWR could yield a margin of 264 Million Dollars. Probably higher margins could be estimated in specific regional situations using more optimistic assumptions. Our analysis thus indicates that the margins likely to be collected from the market, do fall within a range similar to the capital charges required to pay off the initial investment in a large ALWR. We conclude that market conditions have now turned favorable enough, so that if the vendors and their utility clients can build and operate near-term ALWRs at close to their cost targets, then these nuclear plants will likely obtain electricity sales margins within the range required to provide adequate return on and of their original investments. Stated differently, current market conditions can now provide adequate revenues - within the range required to pay for nuclear plant capital costs – when estimated under realistic assumptions. The range of required annual capital charges required to return the initial investment, and the range of likely incoming revenues, now for the first time in many years do (partially) overlap. Thus, detailed specific, local evaluations of the economic prospects of committing to new nuclear plants are now justified, since the initial economic screening studies show positive results.

Conclusion – Outlook for New Nuclear Power Plants

The improved performance records of the operating nuclear plants, the changed utility environment, including the higher natural gas prices regime, and the improved economic position of new nuclear plants – issues discussed above – allow us to draw some general conclusions regarding the near-term outlook for nuclear power in the U.S. and abroad. First and foremost, it has become clear that currently operating nuclear power plant fleets in the U.S. and in other countries East and West form the reliable backbone of base-load generation in those countries, providing 20 percent of all U.S. generation and about 17 percent of global electricity supply. Safe, reliable, and economic operation of the existing plant fleets is the first condition for nuclear capacity expansion. In this regard the various utility self help programs manage by utility organizations like WANO, NEI, the Institute of Plant Operators (INPO) have yielded significant performance improvements as noted above. These improvements have been achieved in face of unprecedented pressures related to electric sector restructuring, deregulation and privatization, the collapse of the power trading industry, the materials problems related to corrosion of reactor pressure vessel top and bottom sections, the terrorist threat following the September 11th attack in the U.S., and the global economic slowdown.

Another factor that will strongly influence the prospects for nuclear power growth is the steady progression towards the solution of the nuclear waste problem. In this regard the approval by the U.S. Congress in July 2002 of the national nuclear waste repository program at the Yucca Mountain site, was a major milestone. While litigation regarding technical details of the waste shipment process to the repository may delay progress in this program, the principle has been set and implementation is but an issue of time, as has previously demonstrated by the military repository near Carlsbad, New Mexico, whose operation is now proceeding smoothly. Similar progress has been achieved in Finland, Sweden and France, and Switzerland, and regional plans are now being developed for Far East regional waste storage programs. Public acceptance of the controlled expansion of future nuclear capacity is now more favorable due to the safe and successful operation of the existing plants, the decreasing availability of other options for bulk power supply such as natural gas, and the progress made in solving the nuclear waste problem. Beyond the safe operation of the existing plants fleet, the improved public perception of nuclear power has been the greatest achievement of the industry over the last ten years.

Beyond the above noted improvements in the general environment some steps are also being taken to increase utility confidence in committing to new nuclear projects. Firstly, the capacity glut created during the 'boom' construction years before the economic collapse of 2001is expected to be worked off towards the end of this decade, leading to new demands for capacity growth at that time. Secondly, transmission line expansions, required to maintain service reliability in face of substantial increases in long-distance wholesale power flows, are not keeping up with the demand in timely fashion, thus creating local shortage situations which require new local generation to alleviate, creating opportunities for future nuclear projects. Thirdly, revised regulations and business models for utility restructuring programs and the national level operation of a mix of some electric sector regulated regions and of deregulated markets in other regions, are being put in place through the FERC initiatives on open transmission access, Regional Transmission Organizations (RTOs), and the proposed Standard Market Design (SMD). While these initiatives will take time to be fully accepted and implemented, they will likely be in place by about 2005 – the early time for new nuclear plant commitments.

Two other initiatives required by utilities interested in committing to new nuclear projects have only partially been implemented. These include: Firstly the national regulations regarding controlling fossil power plant emissions and the acceptance emissions ceiling and reduction goals have not yet been agree upon or implemented.

Any credits from the above that could be applied to non-fossil generation have not yet been promulgated in the U.S., on a national, regional, or state level. Thus utilities do not know the 'rules of the game' in this area, and can not estimate how the avoidance of fossil fired plant emissions can support their case for new nuclear plant commitments. Secondly, no precedent exists yet for the successful completion of a licensing process for a new nuclear plant project, which has not been stopped or interrupted through justified or frivolous litigation. The building blocks of such process are now put in place through the current implementation of the early site permit (ESP) programs, and the NRC's Design Certification (DC) program, and through the promulgation of regulations governing the combined construction and operation licensing (COL) process. No successful demonstration of the COL process has yet occurred, none is expected to be successfully completed before the 2005-2006 period, and some uncertainties regarding the feasibility of success still persist.

Given the above two not insignificant reservations, it is still possible to state that a window of opportunity for utility commitment to new nuclear plant projects may well emerge by 2005, the best opportunity of its kind afforded the industry over the last thirty years. The conditions required for such window of opportunity include: Favorable political climate established through the election of a relatively pro-nuclear Administration by 2005 and the implementation of loan guarantee provisions of the Senate Energy Bill of June 2003; National economic recovery starting in late 2003, driven by tax cuts, interest rate cuts, lower oil prices and increased consumers spending: Continuation of the favorable nuclear plant operating and performance records discussed above, including first and foremost safe plants operation; and Continuing favorable utility situations including strengthening of utility balance sheets, and remaining high natural gas prices. There exists a relatively good likelihood that the above conditions will materialize by 2005. What kind of new nuclear plant projects can we expect by that time?

It is clear that future nuclear projects will be based on standardized designs. In the U.S. even though no standardized plants program has been implemented, save for the two SNUPPS units – Callaway and Wolf Creek, the three Palo Verde units, and the two Commonwealth Edison (now part of Exelon Corporation) two-unit stations of Byron and Braidwood, future trends point to standard plant designs. These trends are based on the utilities realization of the benefits of standardization which have led to the initiation of the ALWR program of 1986, and on the streamlined plant NRC licensing process and its granting of three Design Certificate licenses for standardized plant designs. Internationally there exist several good examples of a standardization program that have demonstrated the benefits of this approach. These include the five series of standard French plant designs, the successful international Canadian 600-740 MWe CANDU-6 & ACR plants program, the Korean KSNP and KSNP+ programs now leading towards the recently announced KNGR reactors program, the Tokyo Electric Power Corporation (TEPCO) BWR-5 and ABWR programs, and possibly the newly emerging Russian international VVER-1000-91 program with units built in Russia, China and India. The Peoples Republic of China (PRC) offers an example of a successful plant standardization program in the southern Guangdong Province, including the six standardized units of the Daya Bay, Ling-Ao and Ling-Ao Phase II stations, funded by the China Light and Power(CL&P) Corporation,. Given this international record, the benefits of standardization in terms of achieving learning curve effects, reducing plant construction duration and costs, and reducing plant O&M costs and outage expenses, are well recognized. It is the intention of the interested U.S. utilities to implement some standardization model in the future U.S. environment.

There are various ways of implementing standardized plant designs within the U.S. utility environment, driven, in part, by the nuclear vendors' experience. One approach is based on a one-off commitment to one nuclear unit at a time, at different utility sites, over a long period of time, depending on demand growth in specific local situations. This approach is based on a standard pre-certified, Nuclear Island (NI) with some utility and vendor flexibility regarding the design of the Balance of Plant (BOP), the choice of the BOP original equipment manufacturers (OEMs), and membership of the construction project team. This limited standardization program is more realistic in that it is geared to fit specific utility needs in a slowly expanding market. Each nuclear unit built enjoys some benefits of standardization, depending on the degree of actual similarity to previously committed units in this series. The overall effect is of a more sure approach, likely to succeed in each separate commitment, however representing higher cost plants due to residually high engineering content on each project, potential lack of continuity in equipment procurement and transfer of construction experience, and high contingency allocation for each stand alone construction job.

On the other extreme we have witnessed an attempt to achieve a large scale standardization program, more similar to the European or East Asian approach. Under this model, several utilities will band together to select a specific reactor design, and a uniform OEM and construction companies team, and build the standard plant design concurrently at several utility sites, some sites accepting more than one unit as part of the original package. All utility members will be charged a series-averaged price for their units and will be levied a high penalty if they opt out of, or reduce their commitment to, the original plants construction program. This concept also envisions maintaining strong Government support for this program, ranging from federally mandated loan guarantees for the entire program, to obtaining regional take-or-pay long-term power purchase agreements (PPAs) for the plants' output. Such a program could achieve the full range of economic benefits expected from a successful standardization program, including potentially significant cost reductions for all units due to multiple equipment item purchases, transfer of learning from one concurrent project to the next, on-site replication cost savings distribution of engineering expenses on all units of this program, and reduced contingency charges. The drawbacks are the political risks inherent in such large scale- long duration program. This program from concept initiation to completion of final unit's construction, could well take sixteen years, if not more. Over this time period one could expect up to four Administrations in Washington, two different Senates and four different House of Representatives at the federal level, as well as multiple similar entities at the regional and state levels. It may not be realistic to assume unity of political purpose among so many diverse bodies over such a long time period, which may include several business cycles.

In evaluating the above two plants standardization models now being considered for the U.S., an obvious trade-off emerges, between the one-off more politically doable but slower and higher costs program, and the full standardization high political risk, but high economic benefits (if successfully implemented) program. It is difficult at this stage to forecast which approach will succeed in the market. The proponents of both programs are now laying the groundwork for their approaches and positioning before real commitments are required beyond the 2005 time frame. All we can say is that the electric utilities sector of the U.S. is so large and energy demands could be high enough that a version of each approach could concurrently and side by side be implemented. Time will tell which approach will succeed, however, it is more likely than not that the goals of the Nuclear 2010 program of the DOE will be fulfilled, at that new nuclear plants will reach commercial operation in the U.S. on or about 2010. .